Near and Far Field Considerations Regarding the Viability of Ocean Carbon Sequestration

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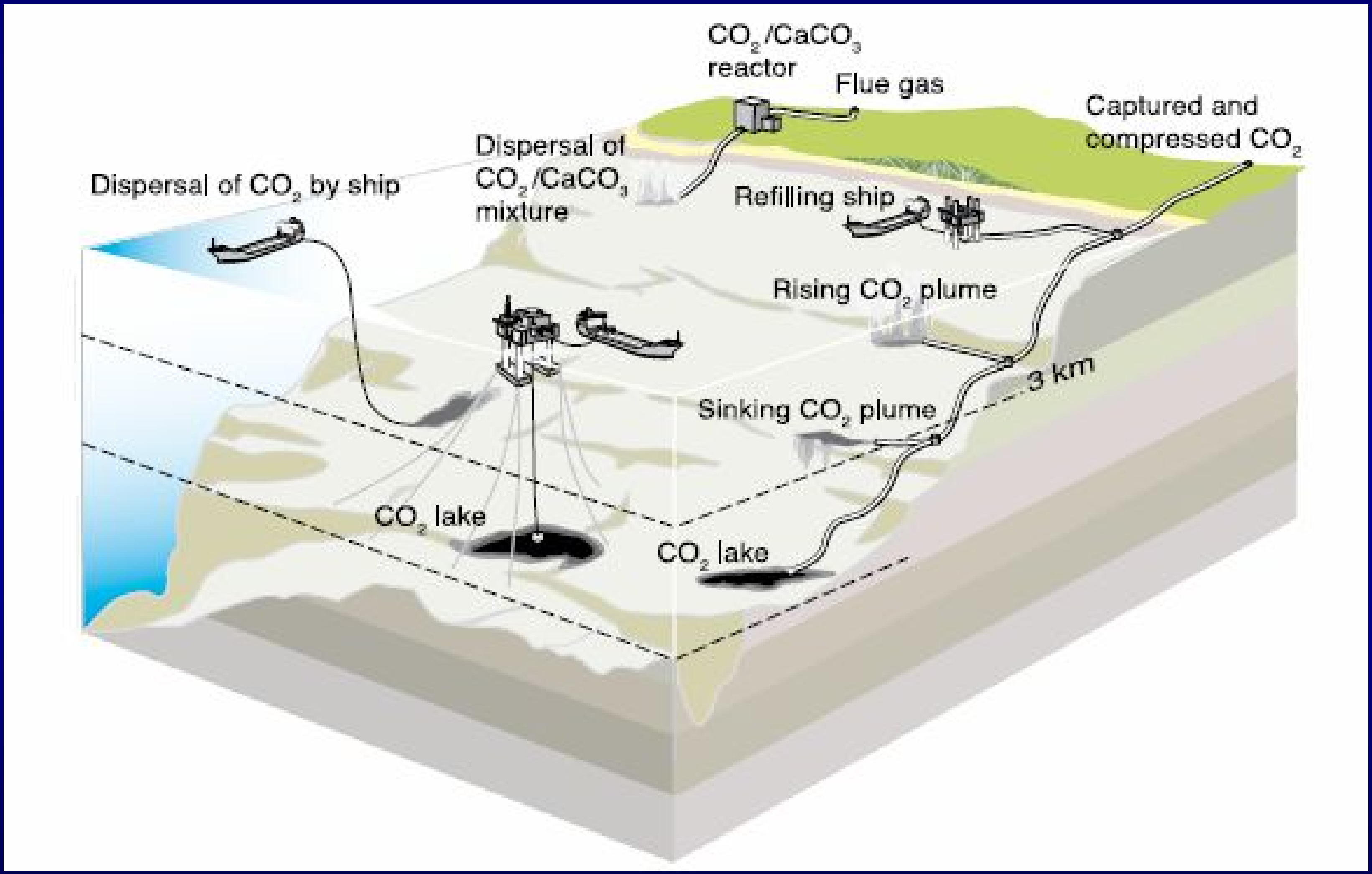
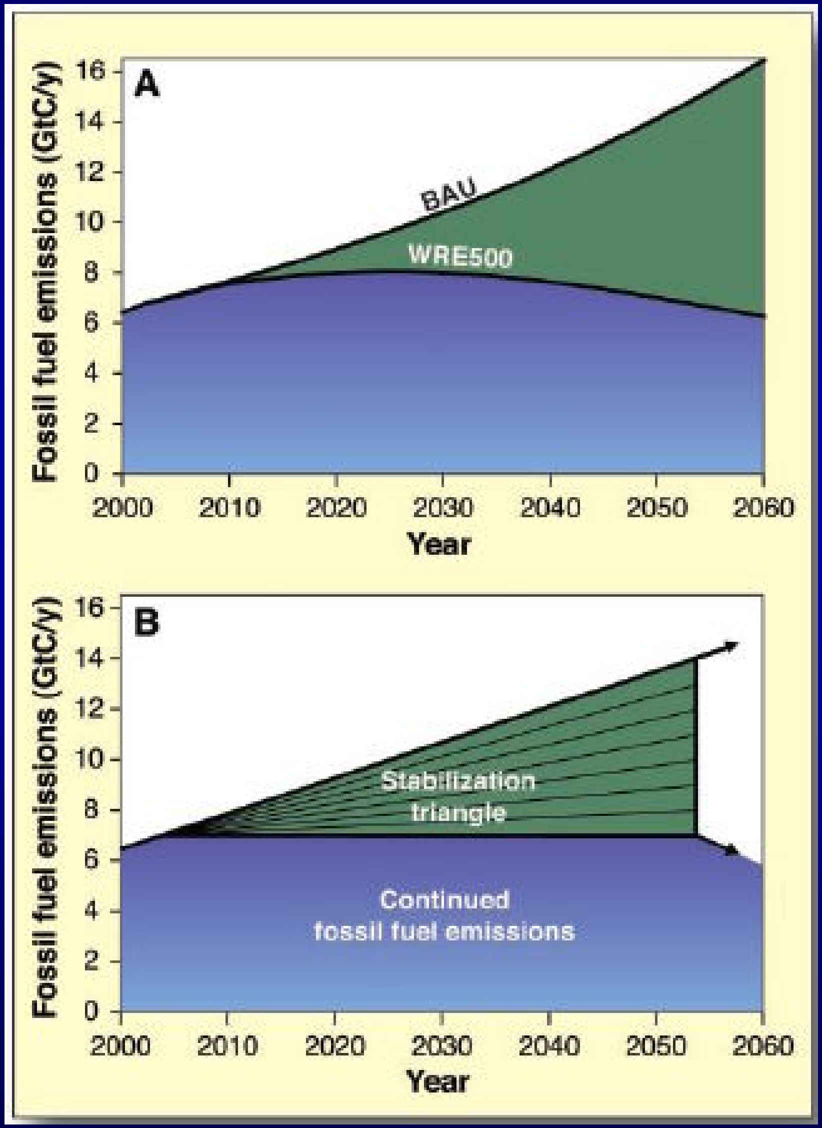
Ocean sequestration options



Source: IPCC Special Report on CC&S, 2005

Context: CO_2 Emissions



Pacala & Socolow (2004) : WRE500 scenario requires avoiding 175 GtC emissions in the next 50 years.

How much of the 175 GtC could be accounted for by ocean sequestration (responsibly)?

Ocean sequestration main criteria

Sequestration efficiency

- How long will the carbon be sequestered from the atmosphere?

Biological impact

- Acute
- Chronic
- Ecosystem

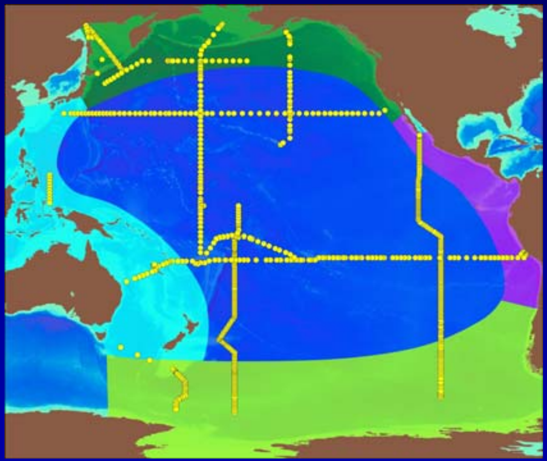
Cost

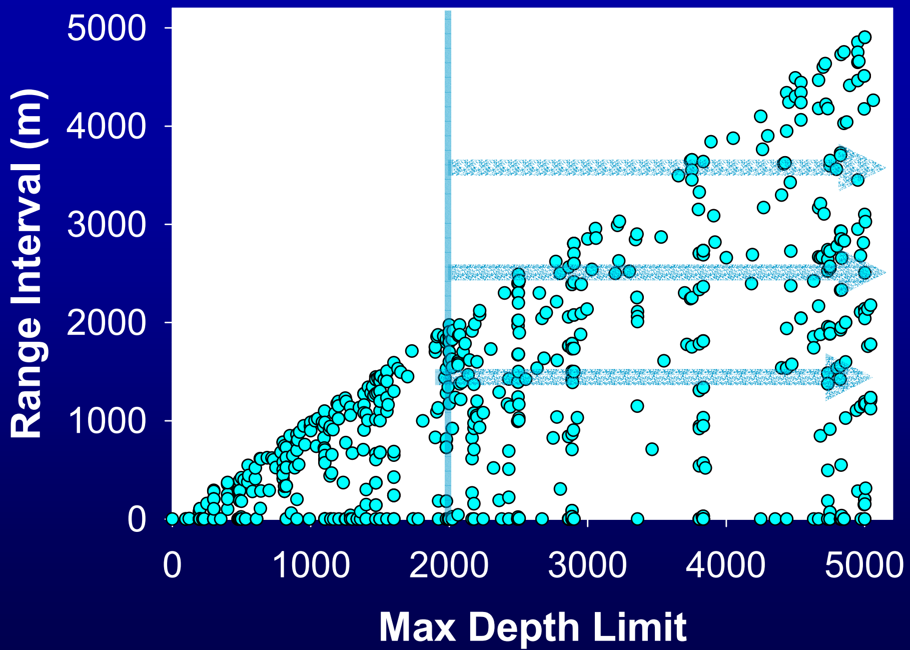
Present Focus

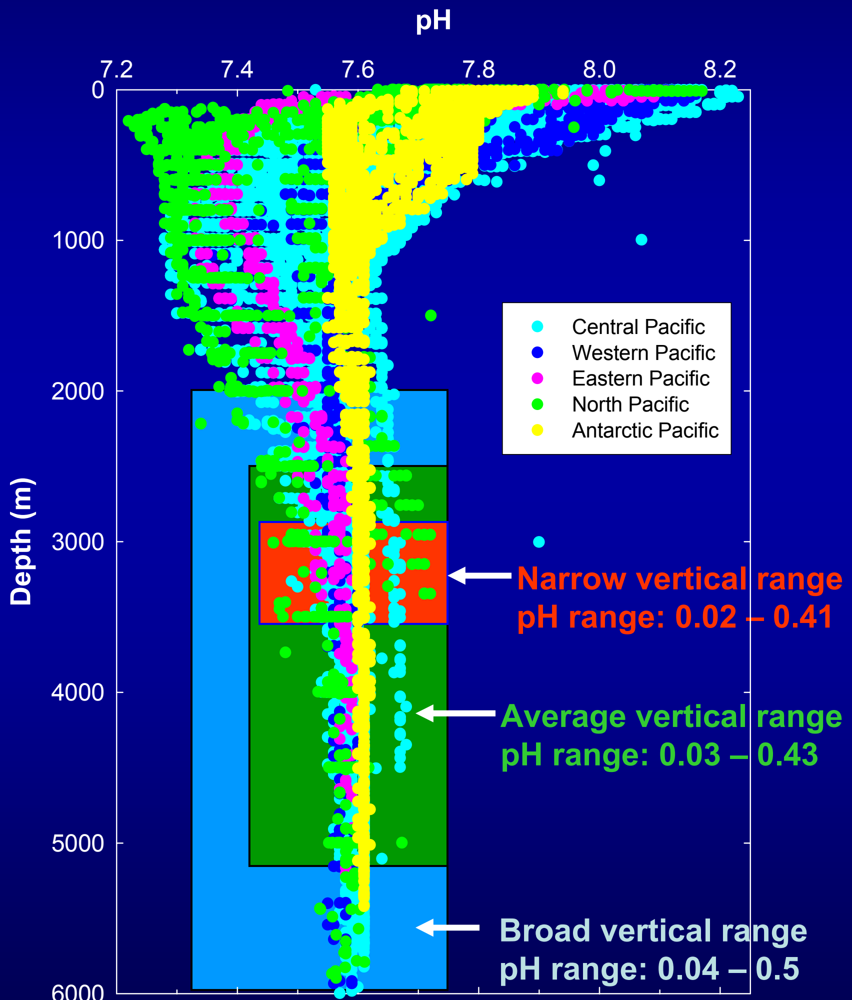
In particular, to what extent do the biological impacts of CO_2-induced pH perturbations limit the viability of ocean sequestration?

Variation in Deep-Ocean pH across Zoogeographic Regions & Bathymetric Ranges

JGOFS/WOCE pH stations + zoogeographic regions (Mironov, 1987)



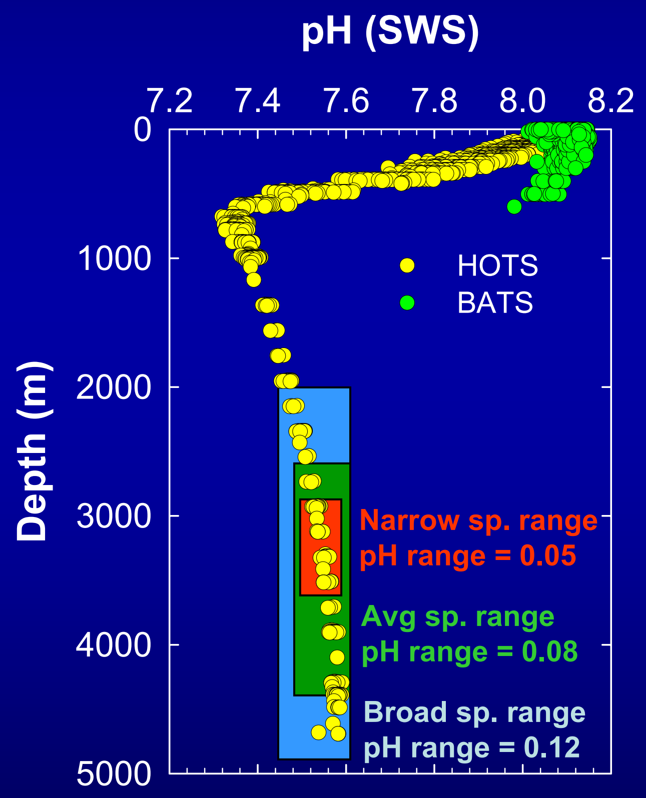




Source: Barry et al. 2005 (AGU Fall Meeting)

Summary of pH variations

Variation at one station

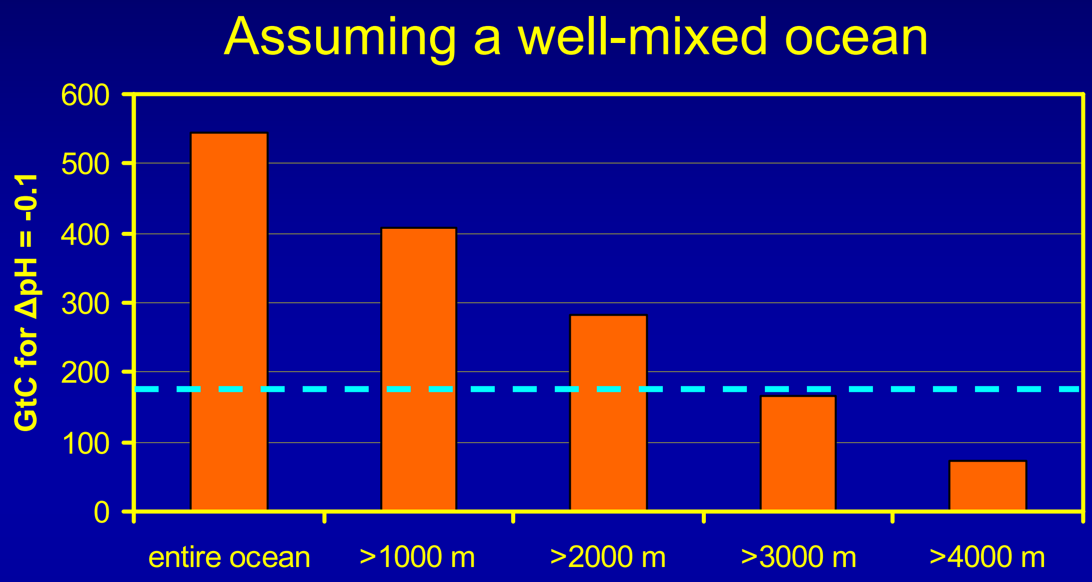


Species Range	Horizontal & Vertical pH Range (Zoographic Regional Mean)	Vertical pH Range (One Station: HOTS)
Narrow	0.16	0.05
Average	0.18	0.08
Broad	0.24	0.12

Assume |ΔpH| < 0.1 ➔ "no ecosystem impact"

Source: Barry et al. 2005 (AGU Fall Meeting)

Expected impacts of a 175 GtC loading?



What about local hot spots (mixing zones)?

We will consider a simple loading scenario:

- 4,000 500-MW coal plants (100 kgCO_2/s each) for 50 years

Simulate 3 discharge scenarios:

- Fixed hydrate plume
- Towed hydrate plume
- Bottom manifold (pipeline)

Stationary dense hydrate plume

CO_2 hydrates

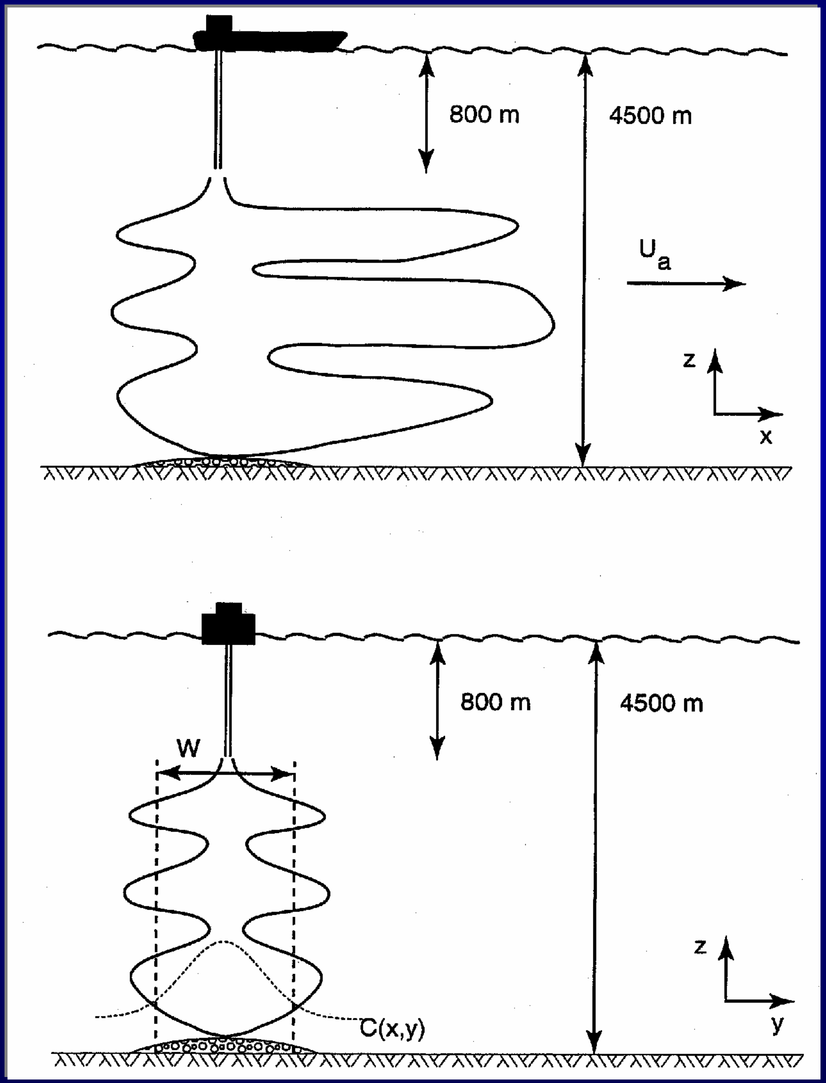
$$CO_2 + nH_2O \xleftrightarrow[T,\,P]{} CO_2 \cdot nH_2O$$

$$n \approx 5.75$$

$$\rho_h = 1100 - 1140\ \text{kg/m}^3$$

- 800 m release depth
- 100 kg/s CO_2
- Pure solid hydrate spheres
- 2.5 cm initial diameter
- 5 cm/s ambient current

3700 m plume depth
(negatively buoyant)



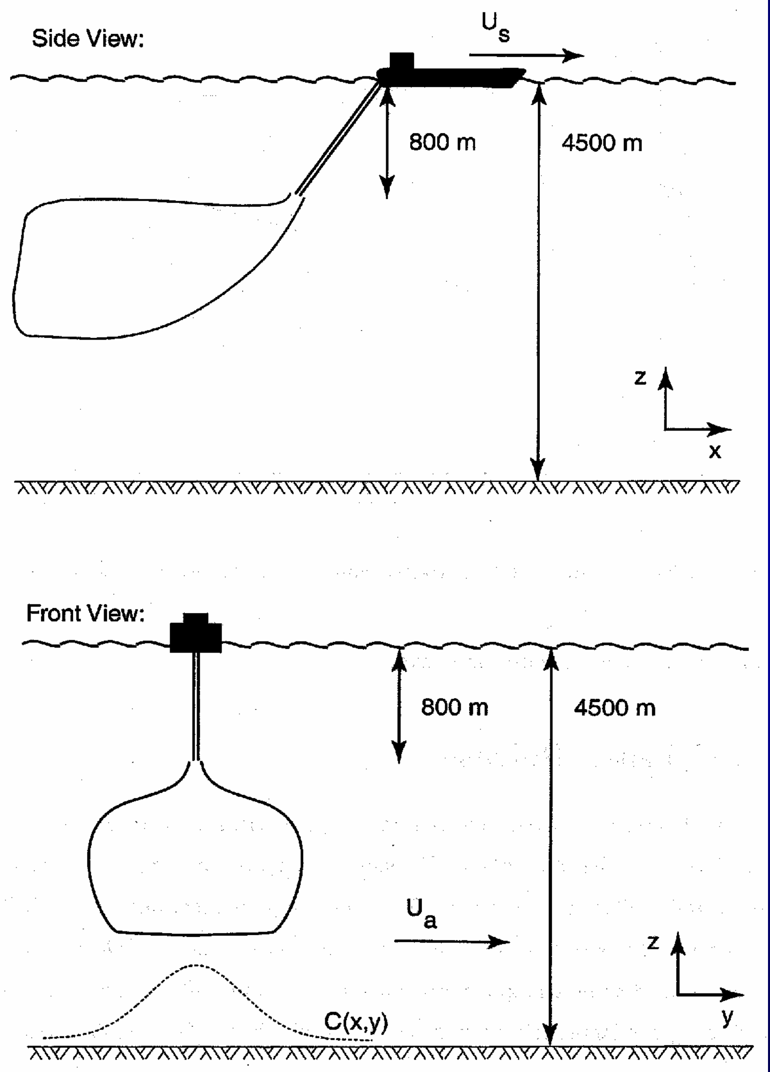
Adams & Wannamaker, JMEE 2005

Towed pipe dense hydrate plume

- 800 m release depth
- 100 kg/s CO_2
- Pure solid hydrate spheres
- 2.5 cm initial diameter
- 3 m/s ship speed
- 5 cm/s ambient current

⬇

1370 m plume depth
(negatively buoyant)



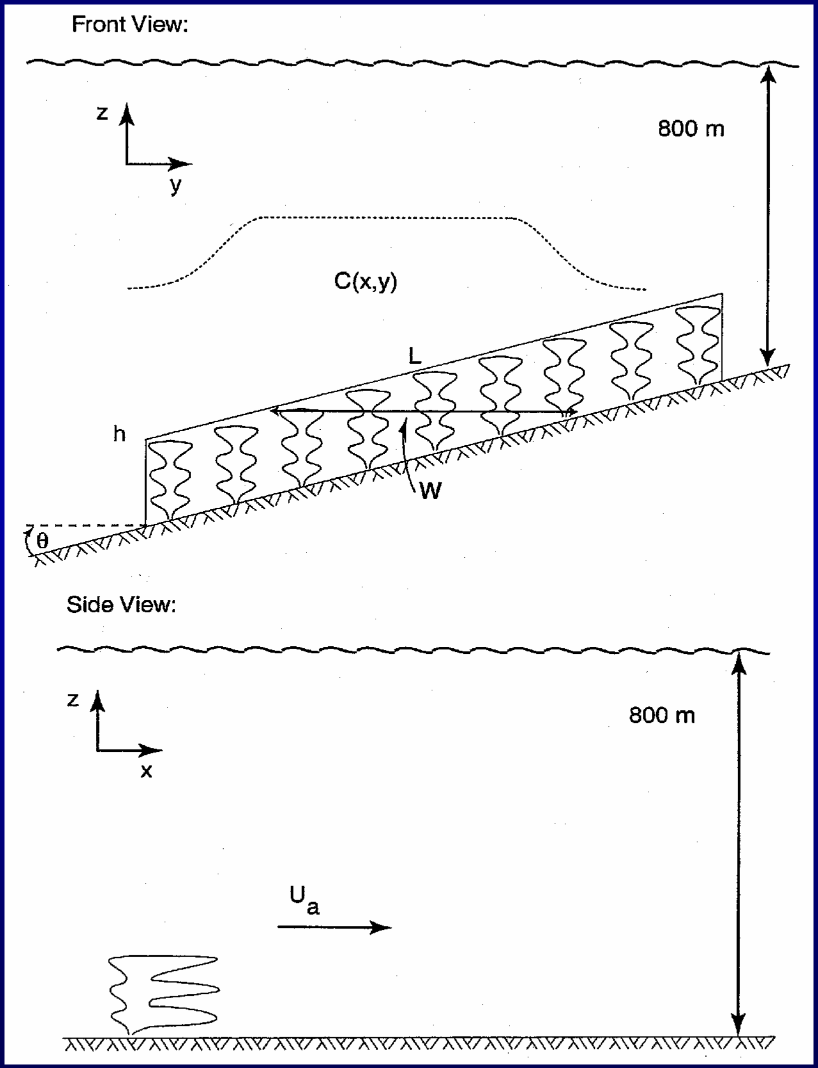
Adams & Wannamaker, JMEE 2005

Bottom manifold release

- 800 - 1200 m release depth
- Slope ~ 0.1
- 100 x 1 kg/s CO_2
- Spaced over 4500 m
- Liquid CO_2 (w/ hydrate film)
- 7 mm droplet diameter
- 5 cm/s ambient current

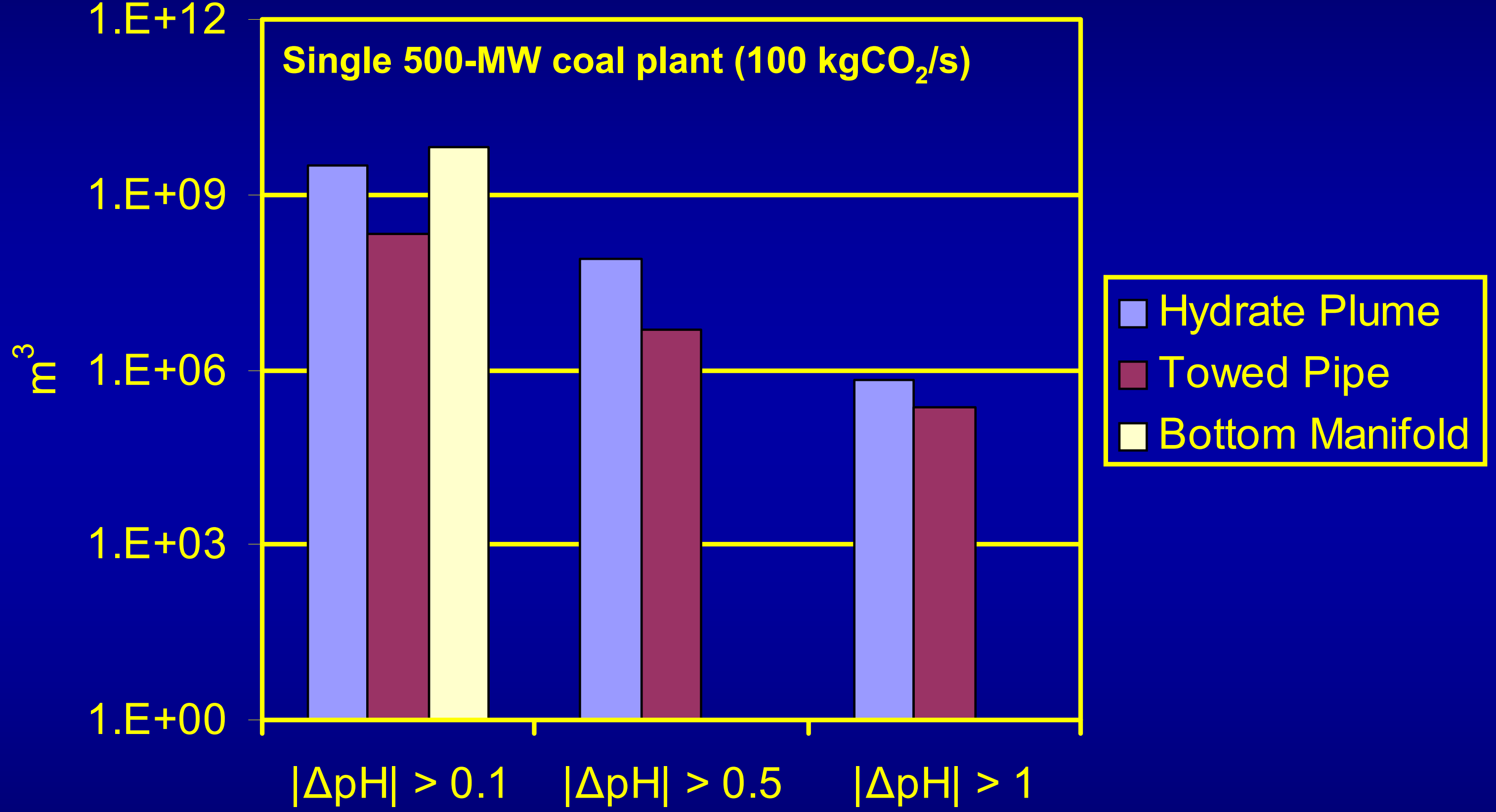
↓

250 m plume height
(positively buoyant)



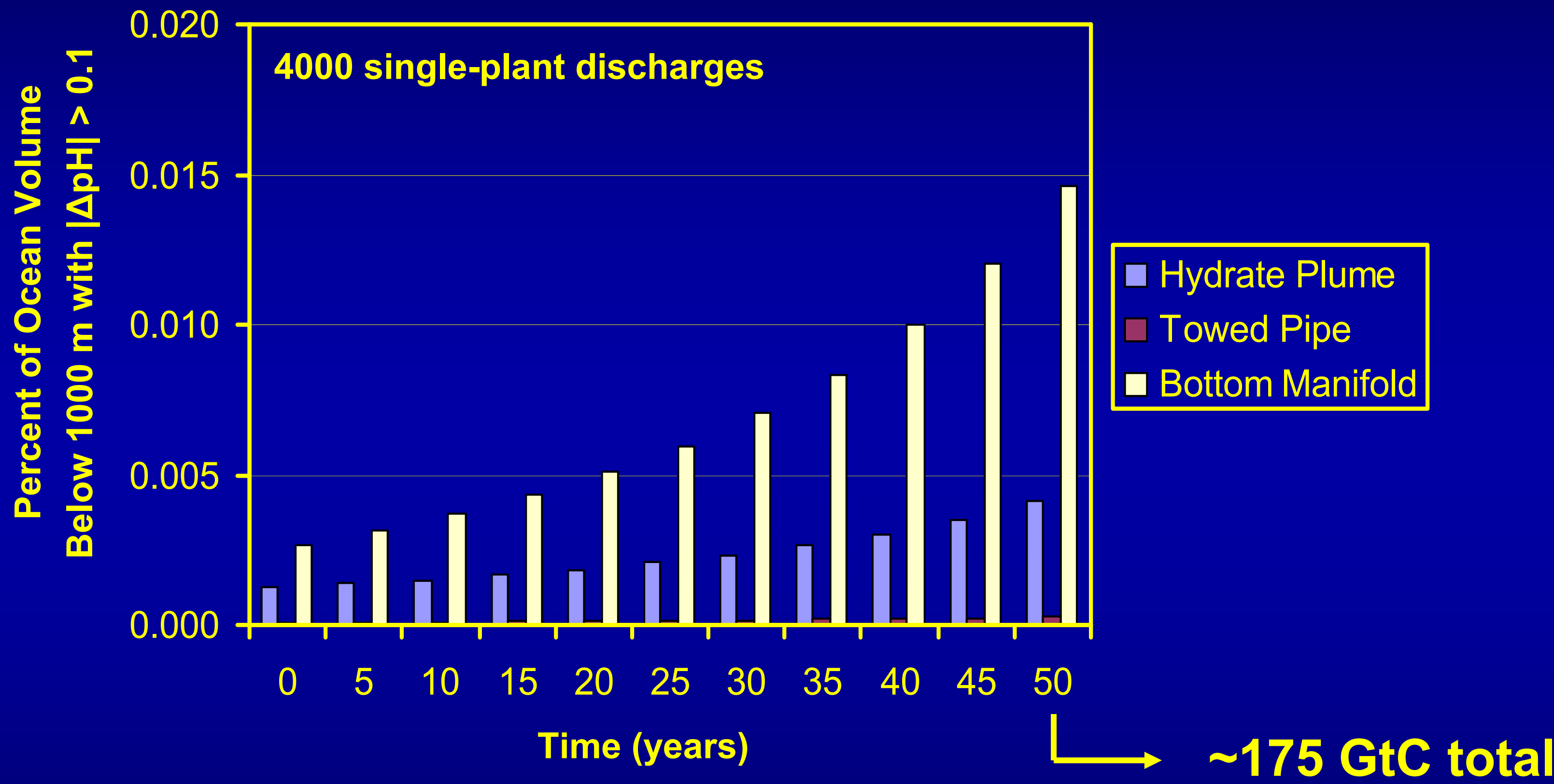
Adams & Wannamaker, JMEE 2005

Initial plume volumes



- **Volume with pH drop > 0.1: ~ 0.2 - 7 km^3**
- **Towed pipe release produces smallest mixing zone**

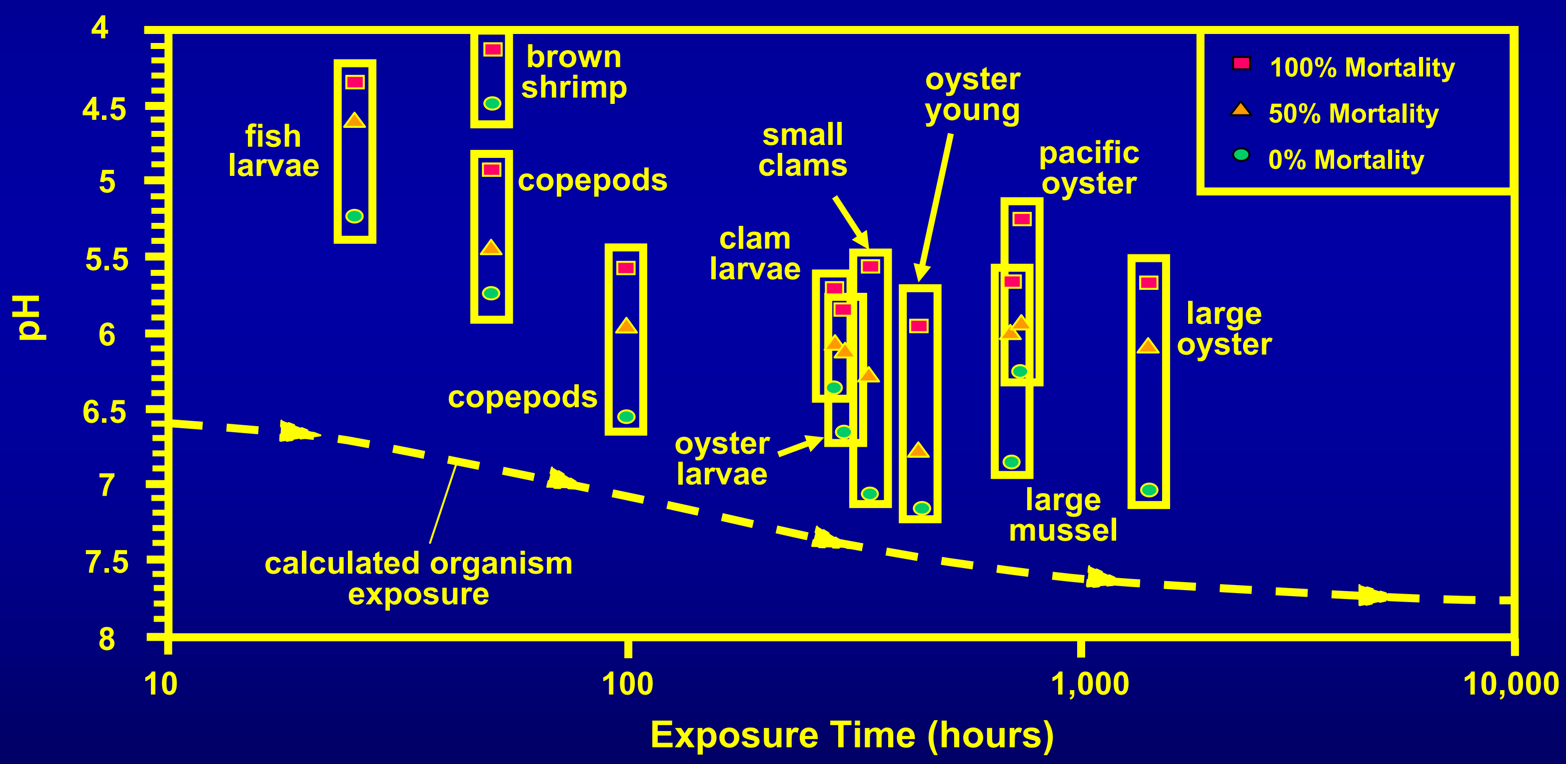
Time varying volumes



- **There is a limit to how long required dilution can be achieved**
- **What about acute effects?**

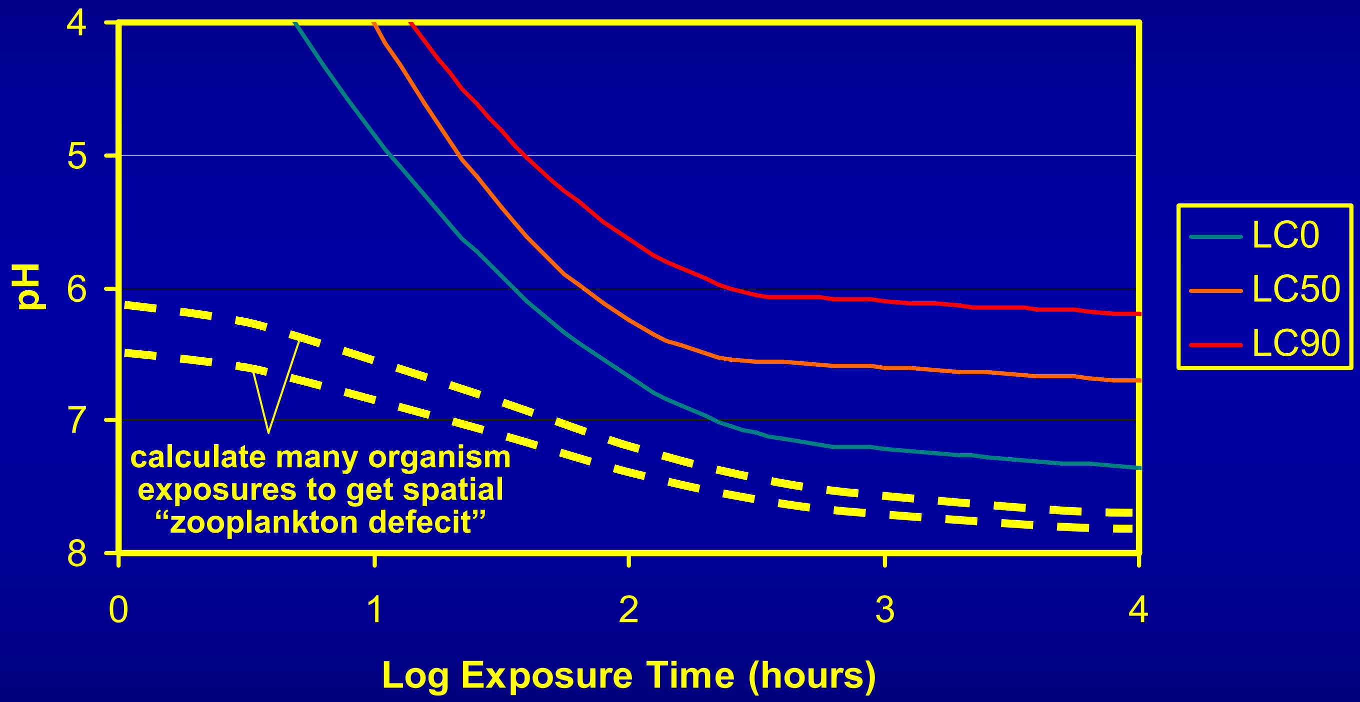
Zooplankton acute mortality data

Auerbach et al. (1997)



“Isomortality” simulations

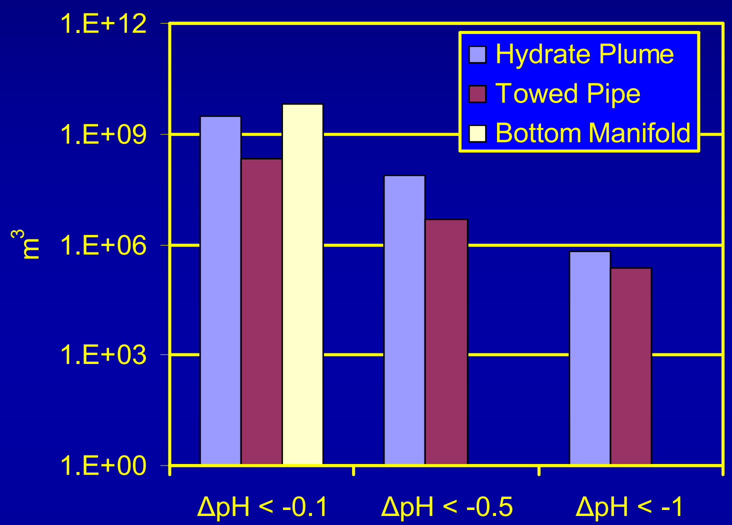
Auerbach et al. (1997), Caulfield et al. (1997)



- For 3 scenarios considered, model predicts negligible acute impacts
- Need to augment with new data: CO_2 stress & deep ocean species

Estimated Acute impacts

Predicting a low impact

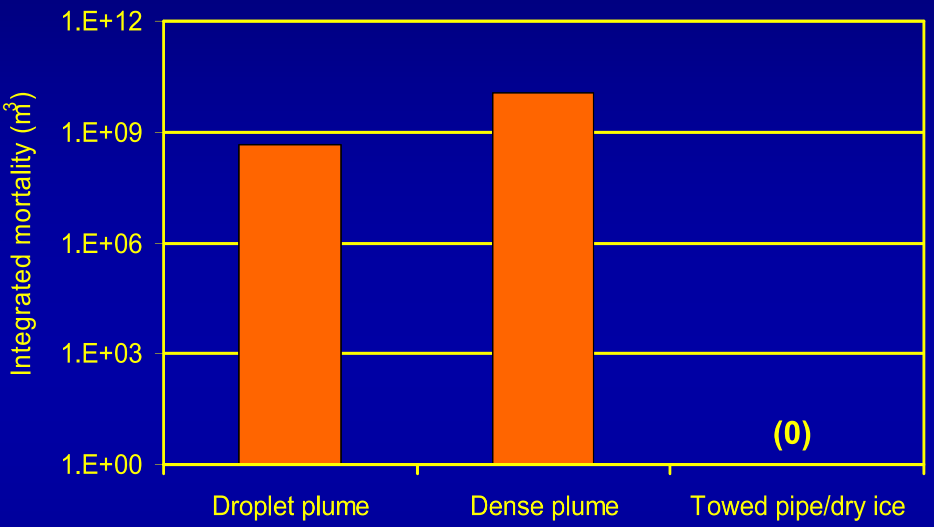


Optimistic dispersion

Optimistic mortality curve

(Refinements ongoing)

Caulfield et al. (1997)



Poor dilution

Optimistic mortality curve

Expect acute impact volumes to be smaller than "ecosystem volume"

Conclusions

- Ocean storage can only be a short to mid-term solution.
- Based on initial acute and ecosystem considerations, it appears that deep ocean sequestration could be engineered to play a significant role in short to mid-term emissions reductions.
- Consideration of more realistic discharge scenarios and biological data are ongoing.

Questions?